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ESTIMATING CROWN FUEL WEIGHTS
OF RED PINE AND JACK PINE

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Estimating Crown Fuel Weights of Red Pine and Jack Pine

6

by James K. Brown

INTRODUCTION

Fuel weight is a major factor influencing the intensity of forest fires. Moisture content, fineness, compactness, and continuity of fuel, as well as prevailing weather conditions, also influence fire intensity since they affect both the amount of fuel available for combustion and the rate of burning. Behavior of fires results from the complex interaction of these factors. Fuel weight, however, is one of the most important considerations in describing fuel hazard since it determines potential fuel energy release and remains reasonably constant over time. Weight of tree crowns, the subject of this paper, is a particularly important component of forest fuels during crown fires or slash fires.

Previous studies have shown that crown weight of many conifer species can be predicted from bole diameter and crown length of individual trees (Kittredge 1944; Storey et al. 1955; Fahnestock 1960; Wendel 1960; and Brown 1963). The trend of increasing crown weight with increasing bole diameter is similar for some species but varies considerably among others because of physical differences in foliage and habit of branching. Very little previous research adequately identifies the variation in crown weight due to site quality and stand density.

This paper describes for red pine (*Pinus resinosa* Ait.) and jack pine (*Pinus banksiana* Lamb.) the relationship between weight of individual crowns and different conditions of site quality and stand density. It also presents a simple method for estimating the crown weights of these species. This method is applicable for estimating both overstory fuel in uncut stands and the amount of slash created by thinning or harvest cutting.

STUDY PROCEDURES AND MEASUREMENTS TAKEN

The data were collected in 1962 and 1963 on the Huron-Manistee National Forests in Lower Michigan. Dominant and codominant trees were randomly selected from 1-inch d.b.h. classes over a range of 2 to 9 inches from stands on good and poor sites at high and low densities. Extremely lopsided crowns, such as occur on trees at the border of plantations, were not accepted.

Site index was determined from the 5-year internode length above breast height for red pine (Day et al. 1960) and from tree height at age 50 for jack pine. The site index of sampled red pine stands averaged 72 on good sites and 49 on poor sites; for jack pine it averaged 62 on what was termed good sites and 43 on poor sites.

Stand density was measured (1) for each red pine by tallying all trees within a 1/40-acre plot, including the sample tree located at the plot center, and (2) for each jack pine by computing the average spacing between the sample tree and all surrounding competing trees. For good and poor sites combined, the sampled stands had the following number of trees per acre for high-density and low-density conditions:

NOTE: The author is Associate Fire Control Specialist at the Lake States Forest Experiment Station, which is maintained at St. Paul, Minn., by the Forest Service, U.S. Department of Agriculture, in cooperation with the University of Minnesota.

	Diameter class (inches) 2-4	5 and 6	7-9
High-density stands			
Red pine	1,190	980	690
Jack pine	2,340	1,090	810
Low-density stands			
Red pine	550	400	440
Jack pine	490	360	300

Altogether, 103 red pines were selected from 13 plantations between 11 and 45 years old, and 95 jack pines from 9 plantations and natural stands between 15 and 47 years old. Stand age was based on age of trees beginning with 3-year-old seedlings.

Trees were severed at ground level and all branches lopped flush with the bole. Tops of trees were cut off at a diameter of 1.5 inches and, together with the branch material, were weighed by means of a dynamometer suspended from an A-frame.

Live crown length, tree height, d.b.h., age, crown competition, and site index were recorded for each sample tree.

Estimates of needle weight for individual red pines were obtained by stripping foliage from 1 branch per whorl from 24 trees of different diameters and stand conditions. These needle samples were weighed, then expanded to a per-tree basis according to the number of branches in each whorl. Moisture samples of branchwood and needles showed that moisture content averaged 110 percent of dry weight. By means of this figure, green weights of all red pine crown material were reduced to dry weights.

Needle weight for individual jack pines was also estimated from 24 trees of different diameters and stand conditions. For this species, however, the branches from the upper two-thirds of the tree were kept separate from those of the lower one-third; the latter was expected to have, and actually did have, a lower proportion of needle weight to branchwood. For each of these two parts of the crown, sample branches were chosen and stripped of needles. Branches and foliage were then weighed. The green needle weight was next calculated as a percentage of the total. This percentage, applied to the total weight of all branches and foliage in that portion of the tree, gave the total green needle weight. Dry weights were obtained on an individual tree basis, using moisture content percentages obtained from foliage and branchwood for the adjustment.

Estimates of needle weight for both species are representative of foliage conditions from the time of needle fall in the autumn to about July, when new summer growth becomes appreciable. They do not include new foliage developed during the summer.

PREDICTION OF CROWN MATERIAL

The Variables Studied and Equations Developed

The data for each tree species were subjected to linear regression analyses (table 1). In most cases logarithmic transformation of dependent variables improved estimates.

The best equations for estimating crown weight per tree and per cord with the smallest standard error are shown in table 2. Although only trees with dominant and codominant crowns were sampled, the findings of this study probably apply to intermediate and suppressed trees as well; the relationship between foliage or crown weight and dimensions of the stem has been shown to be similar for all crown classes (Kittredge 1944; Storey et al. 1955). Normally dominant trees have large crowns and large diameters, while suppressed trees have small crowns and small diameters.

Live Crown Weight Per Tree

Of all the independent variables tested, d.b.h. and crown length x d.b.h. resulted in the most precise relationships with crown weight per tree. D.b.h. was the best single predictor of crown weight per tree for both red and jack pines. This proves helpful in actually predicting crown fuel weights because d.b.h. is easily measured.

TABLE 1. — *Crown fuel variables and tree characteristics examined for red pine and jack pine stands growing on good and poor sites at high and low densities; X means the variable was investigated*

Item	Jack pine	Red pine
INDEPENDENT VARIABLES		
D.b.h.	X	X
Tree height	X	X
Crown length	X	X
Bole length	X	
D.b.h. x crown length	X	X
D.b.h. x tree height	X	X
D.b.h. x bole length	X	
Age	X	X
Site index	X	X
Basal area/acre	X	X
Number of trees/acre	X	X
DEPENDENT VARIABLES		
Dead branch weight/tree	X	
Live crown weight/tree	X	X
Total crown weight/tree (dead branches plus live crown)	X	
Live crown weight/cord		X
Total crown weight/cord	X	

TABLE 2. — *Equations for predicting the crown weight (lbs. oven-dry basis) per tree and per cord from d.b.h., number of trees per acre, site index, and age of stand for red and jack pines*

Species	Equation[1]	R² *	Standard error of estimate
Red pine	Log (live crown weight/tree) = .9990 + .0946 (d.b.h.) + .003614 (SI) — .0002722 (trees/ac.)	.86	.0961
Red pine[2]	Log (live crown weight/cord) = 5.2947 — .0318 (stand age) — .000162 (trees/ac.) — .0160 (SI)	.78	.1119
Jack pine	Log (total crown weight/tree) = .8234 + .133 (d.b.h.) + .003393 (SI) — .0001127 (trees/ac.)	.90	.1234
Jack pine	Log (live crown weight/tree = .9733 + .1148 (d.b.h.) — .0001556 (trees/ac.)	.82	.1605
Jack pine	Log (dead branch weight/tree) = .2087 (d.b.h.) — .0978	.78	.2491
Jack pine[2]	Log (total crown weight/cord) = 5.1125 — .0269 (stand age) — .000166 (trees/ac.) — .0135 (SI)	.78	.1260

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[1] *SI = site index.*

[2] *In addition to sampling error, an unknown amount of error exists in this equation because crown weight per cord was calculated from volume table values, not measured for each tree.*

* *R^2 measures the proportion of the variation about the mean accounted for by the independent variables.*

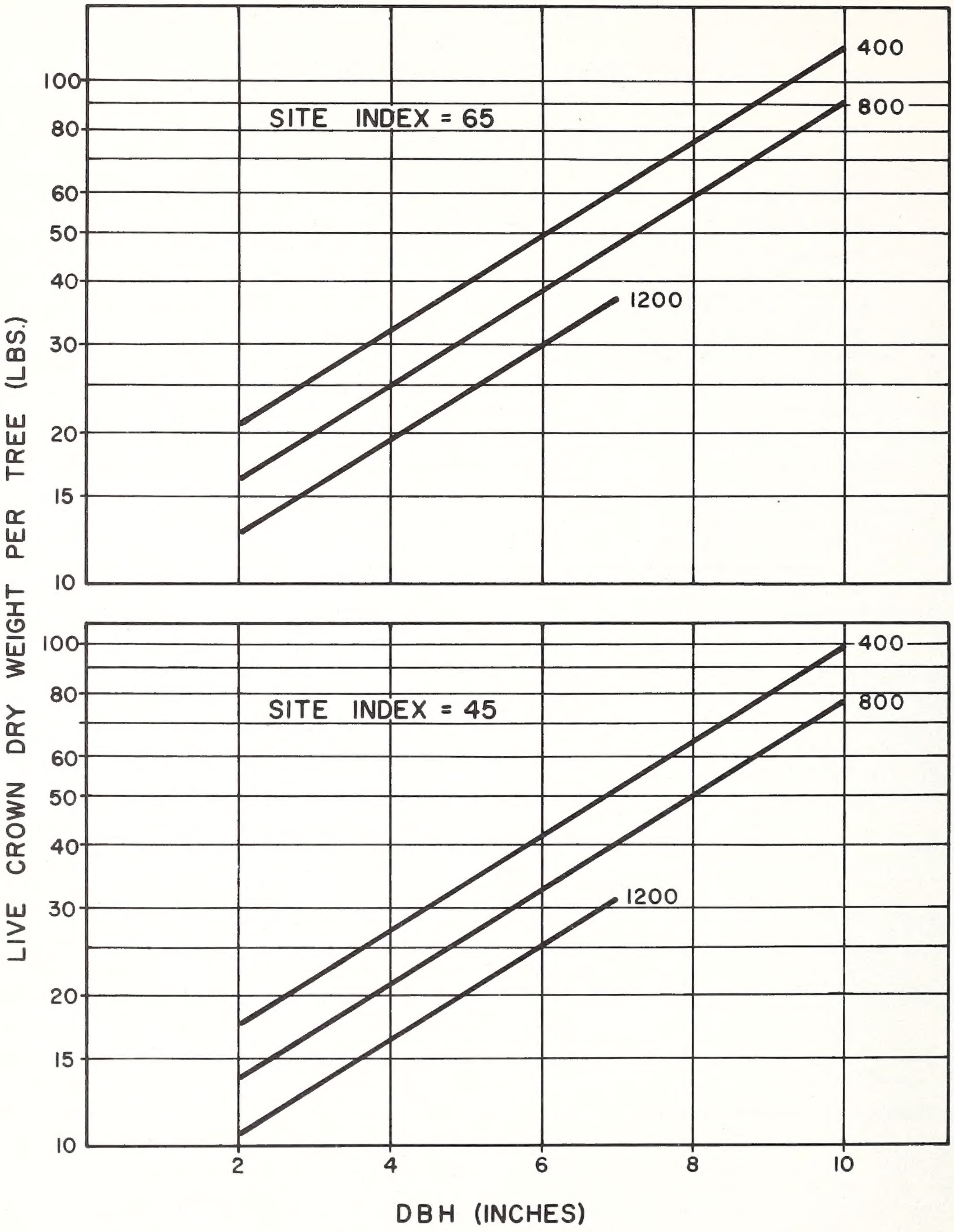


FIGURE 1. — Live crown weight of red pine trees for different diameters, numbers of trees per acre, and two site indexes. Equations for these curves are shown in table 2.

Neither number of trees nor basal area per acre merited use as single predictors of fuel weights. For use in multiple regression equations, number of trees per acre, however, was a considerably better measure of stand density than was basal area per acre.

Figure 1 shows the relationship between live crown weights of red pine and d.b.h. for two site indexes and three stand densities. Comparing trees of the same d.b.h., individual crowns on good sites weigh more than crowns on poor sites, and crowns from low-density stands weigh more than crowns from high-density stands. This is also true for live crown weights of jack pine.

Total Crown Weight Per Tree

Dead branches on jack pines were weighed and added to live crown material, yielding values of total crown weight per tree. The relationship between total crown weights of jack pine and d.b.h. for two site indexes and four stand densities is shown in figure 2. As with live crowns for trees of the same d.b.h., individual total crowns on good sites weigh more than those on poor sites, and total crowns from low-density stands weigh more than those from high-density stands.

The weight of dead branches on individual trees related closely to d.b.h. Site and stand density did not significantly improve prediction of dead branchwood per tree over the prediction based on d.b.h. alone.

An investigation by LaMois (1958) provides estimates of the weight of dead branches on red pine (see section on Fuel Quantity Application).

Crown Weight Per Cord

In an attempt to find an easy way of estimating the amount of slash generated from logging operations, crown weight per cord was computed and held as a dependent variable in regression with age and d.b.h. Age of stand correlated highest with crown weight per cord, and since age is often known or easily determined by forest managers, it makes a convenient predictor.

Crown weight per cord was obtained by first determining the cordwood volume in each sample tree, then calculating the number of trees per cord (1.0 divided by cordwood volume per sample tree), and finally multiplying this volume by crown weight per tree. Volume for each sample tree was arrived at from a cordwood volume table based on a 3-inch merchantable top (Gevorkiantz and Olsen 1955).

At any given age, over the range dealt with here, the amount of crown weight per cord of red or jack pine was greater on poor sites than on good sites (figs. 3 and 4). Trees on poor sites with small diameters contained considerably less merchantable cordwood volume than the larger trees on good sites; hence crown weight per cord was greater on poor sites. Similarly, crown weight per cord in high-density stands is less than in low-density stands because tree competition in dense stands retards branch growth on individual trees.

Needle Quantities

The percent needle weight in live crowns averaged 43 percent for red pine and 21 percent for jack pine, a marked difference between the species. Neither site quality nor stand density greatly influenced the proportion of needle weight to live crown weight, particularly with jack pine (fig. 5). Small but reliable differences in percent needle weight due to growing conditions were observed for red pine.

Crowns from good sites held more foliage per unit weight of branchwood than those from poor sites. Similarly, crowns from high-density conditions contained more foliage per unit weight of branchwood than those from low-density conditions. Even though the ratio of needles to branchwood was higher in high-density stands, trees grown in these stands yielded a smaller total quantity of needles than trees grown under light competition.

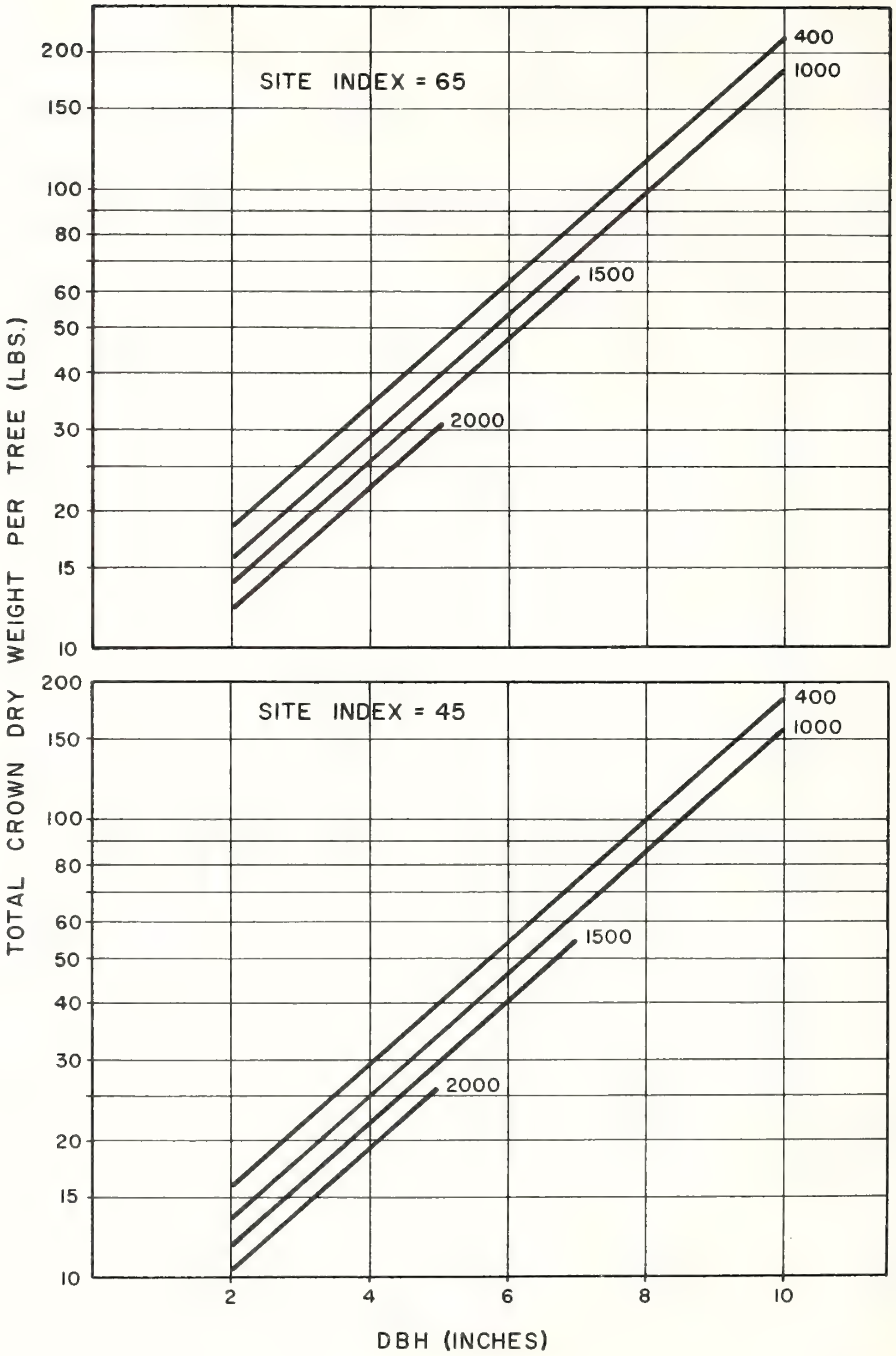


FIGURE 2. — Total crown weight (dead and live branches) of jack pine trees for different diameters, numbers of trees per acre, and two site indexes. Equations for these curves are shown in table 2.

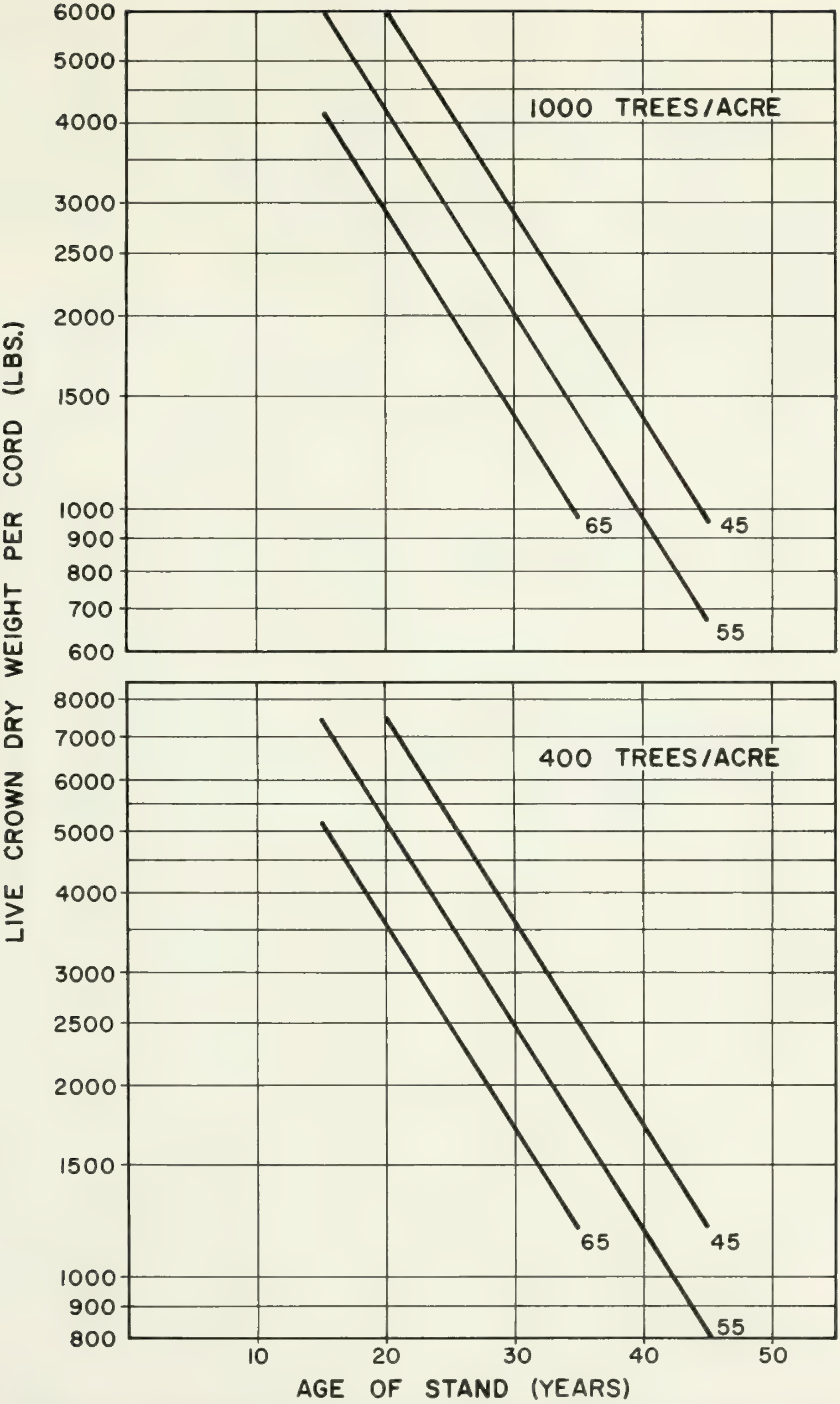


FIGURE 3. — Red pine live crown weight per cord according to age of stand, site index, and two stand densities. Equations for these curves are shown in table 2.

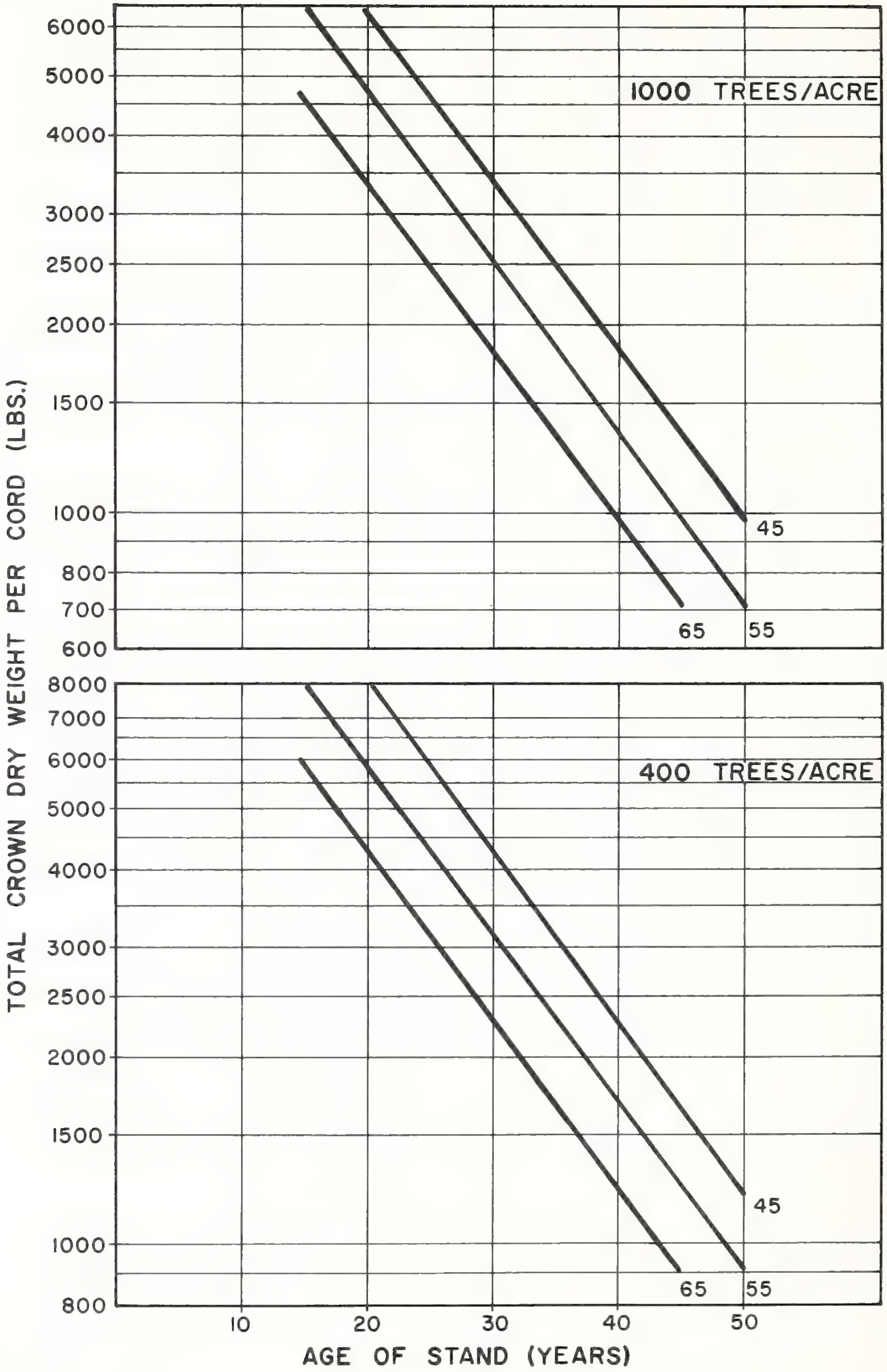
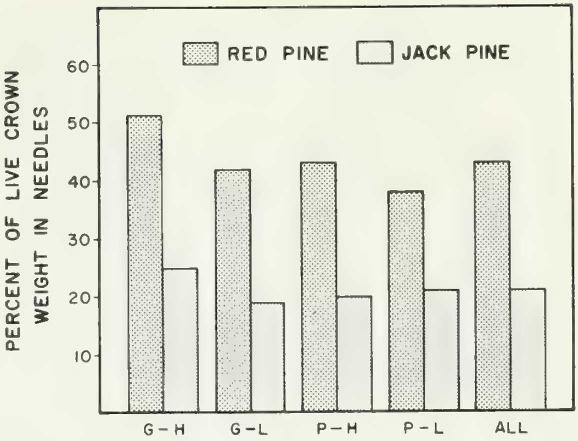


Figure 4. — Jack pine total crown weight (live and dead branches) per cord according to age of stand, site index, and two stand densities. Equations for these curves are shown in table 2.

FIGURE 5. — Percent live crown weight in needles for red pine and jack pine on good (G) and poor (P) sites at high (H) and low (L) densities. Actual values for site index and stand density are averages of field conditions sampled and are not exactly the same for both species. Percent needle weight is based on 6 observations in each stand condition, or 24 observations overall with a standard error of the mean of 1.5 percent.



FUEL QUANTITY APPLICATIONS

Slash Accumulations

The quantity of slash resulting from a cutting operation can be estimated by (1) determining the site and density of the stand, (2) multiplying the number of trees harvested in each diameter class by the proper crown weight per tree, which is obtained from figures 1 or 2 or the appropriate equations, and (3) totaling these results through all diameter classes. If site index or stand density falls between standards used in this study, interpolation of crown weight will improve the outcome.

To include dead branches on red pine in estimating accumulation of slash per acre, results of LaMois' (1958) study can be applied. For red pine 4 inches in d.b.h. and larger, 5,000 pounds (dry weight) of dead branchwood per acre may be found on good sites and 2,500 pounds on poor sites. Red pine stands older than 30 years probably support amounts greater than these.

Another way of determining the amount of slash resulting from a cutting operation, knowing age of stand, is to calculate the crown weight per cord, using figure 4 or 5 or the appropriate equation. Again, interpolation of crown weight between site and density standards presented in the charts will improve results. Number of cords harvested multiplied by the crown weight per cord equals the quantity of slash created. Several examples of predicted crown fuels encountered in red and jack pine stands are described in table 3 and figures 6 and 7.

Fire Spread and Intensity

Quantity of fuel substantially affects rate of spread and fire intensity. Several findings from a study by Fahnestock (1960) should be generally applicable to red and jack pine crown fuels. He reported that, as a rule-of-thumb, rate of spread in slash over a wide range of relative humidities but at low wind velocities increases 6 percent for each ton of fuel added to an acre. This holds about equally true for fresh and 5-year-old slash (Fahnestock and Dieterich 1962). Fuel quantity of Rocky Mountain species had a stronger effect on fire intensity than on rate of spread. Fire intensity was three times higher in test plots of 32.5 tons per acre than in plots of 20 tons per acre (Fahnestock 1960).

TABLE 3. — *Dry weight per acre of live and dead crown material (excluding bolewood over 1.5 inches in diameter) estimated for three stand conditions typical of pine plantations in Lower Michigan*

Species	Silvicultural condition	Age	Site index	Trees per acre	Needle weight	Total crown weight
		Years		*Number*	*Tons*	*Tons*
Jack pine	Slash from clear-cut operation	50-60	45	500	6½	30
Red pine	Uncut	25	70	1,000	9	20
Red pine	Slash after thinning from 150 sq. ft. to 100 sq. ft. of basal area	25	70	1,000	3½	8
Red pine	Uncut	15	70	1,200	5	10

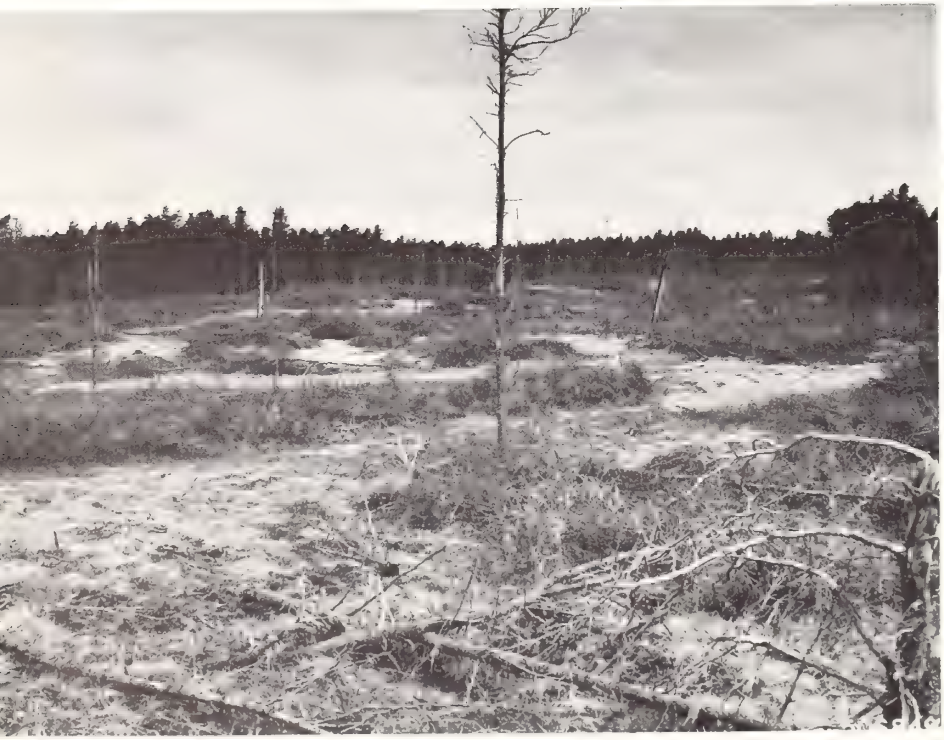


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FIGURE 6. — This 40-year-old jack pine stand on a poor site was severely damaged by the pine tortoise scale (*Toumeyella numismaticum* Pettie and McD.). Salvage logging left 23 tons of slash per acre. Picture taken 3 years after logging.

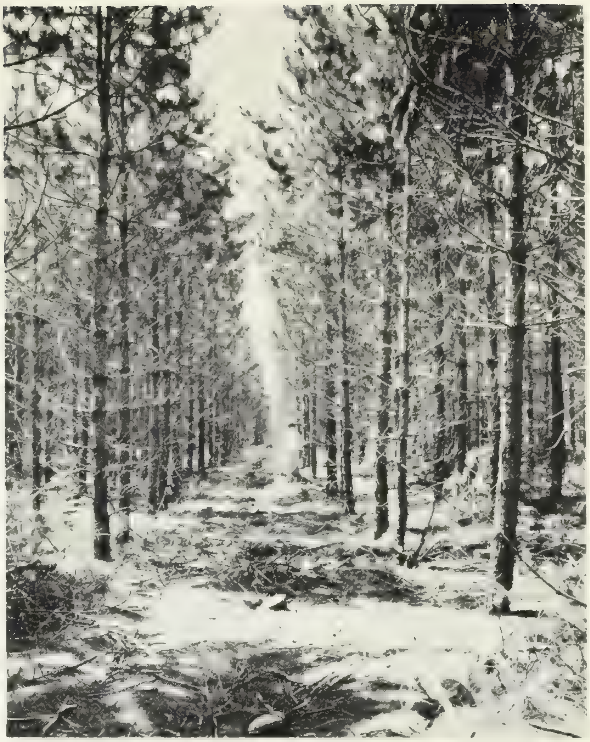

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FIGURE 7. — Commercial thinning to 100 square feet of basal area in this 25-year-old red pine plantation containing 1,000 trees per acre on a good site created approximately 8 tons of slash per acre (excluding bolewood over 1.5 inches in diameter).

SUMMARY AND CONCLUSIONS

This paper shows the effect of site and stand density on the crown size of individual red pine and jack pine trees and provides a means of estimating crown fuel weights.

Of all the independent variables examined, d.b.h. related to crown weight per tree with the smallest standard error.

Site and stand density exerted notable influence on crown weight per tree. Similar to normal forest yield-table trends, volume production of crown material for both red pine and jack pine was greater on good sites than on poor sites. It was also greater in low-density stands than in high-density stands. Graphs and equations are presented for predicting crown weight per tree using d.b.h., site index, and stand density as multiple independent variables.

Graphs and equations are also presented for estimating the quantity of crown material per cord of merchantable wood from stand age, stand density, and site index. All three of these factors influence crown weight per cord.

Results of this study show that estimated amounts of foliage and branchwood, on an acre basis, vary according to age and growing conditions of the stand. The expected amount of live crown on an acre composed predominantly of red pine or jack pine of pulpwood size ranges from 7 to 20 tons dry weight.

The proportion of live crown weight composed of needles averaged 43 percent for red pine and 21 percent for jack pine. Site and stand density exerted a slight influence over this proportion.

Research on the physical characteristics of fuels is directed toward understanding fire behavior in such a way that diverse levels of fire hazard can be recognized, particularly circumstances encouraging to high-intensity and conflagration-type fires. With increasing knowledge, a national system of rating fire ignition, intensity, and blowup potential may eventually be possible, but as yet the intricacy of fire and fuel relationships requires further exploration. A system of classifying the vertical and horizontal distribution of forest fuels according to their particle size and surface area would aid considerably in solving problems of predicting fire behavior.

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